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The Effects of Fatigue on Soccer Skills Performed During a Soccer Match Simulation

Mark Russell, David Benton, and Michael Kingsley

Purpose: This study examined the effects of exercise-induced fatigue on soccer skills performed throughout simulated match play. ***Methods:*** Fifteen academy soccer players completed a soccer match simulation (SMS) including passing, dribbling, and shooting skills. Precision, success rate, and ball speed were determined via video analysis for all skills. Blood samples were obtained before exercise (preexercise), every 15 min during the simulation (15, 30, 45, 60, 75, and 90 min), and 10 min into half-time. ***Results:*** Preliminary testing confirmed test-retest repeatability of performance, physiological, and metabolic responses to 45 min of the SMS. Exercise influenced shooting precision (timing effect: $P = .035$) and passing speed (timing effect: $P = .011$), such that shots taken after exercise were 25.5 ± 4.0% less accurate than those taken before exercise and passes in the last 15 min were 7.8 ± 4.3% slower than in the first 15 min. Shot and pass speeds were slower during the second half compared with the first half (shooting: 17.3 ± 0.3 $m \cdot s^{-1}$ vs 16.6 ± 0.3 $m \cdot s^{-1}$, $P = 0.012$; passing: 13.0 ± 0.5 $m \cdot s^{-1}$ vs 12.2 ± 0.5 $m \cdot s^{-1}$, $P = 0.039$). Dribbling performance was unaffected by exercise. Blood lactate concentrations were elevated above preexercise values throughout exercise (time of sample effect: $P < .001$). ***Conclusions:*** These findings demonstrate that soccer-specific exercise influenced the quality of performance in gross motor skills, such as passing and shooting. Therefore, interventions to maintain skilled performance during the second half of soccer match play are warranted.

Keywords: football, intermittent, passing, shooting, dribbling, technical, performance

Physical performance has been observed to decline in the latter stages of real[1–3] and simulated[4] soccer match play, where soccer-related fatigue is associated with diminished work rates,[2,3] declining muscular force output[4] and reduced performance in high-intensity exercise.[1] However, limited research exists concerning the effects of fatigue on technical performances (ie, skills) during soccer match play. This is somewhat surprising considering that a disproportionate number of goals are

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scored in the last 15 min of a match,[5] suggesting that a relationship exists between match-related fatigue and technical proficiency.[6]

The majority of studies that examine the effects of exercise on soccer skills have assessed technical proficiency before and after exercise.[6–8] Moreover, previous studies have employed exercise protocols that are not representative of the demands of match play because they do not include soccer-specific movement patterns[6] or half-time.[7,8] Consequently, little evidence exists to evaluate the effects of soccer-specific exercise on skills performed throughout game-play.

Rampinini et al[9] observed a decline in short-passing performance throughout soccer match play that was attributed to the effects of fatigue. However, Currell et al[10] reported that kicking performance was maintained during simulated match play. Although skills were performed at six time points during soccer-specific exercise, the use of criterion-based outcome measures (ie, scored for accuracy against set criteria with time faults added for errors), which is a common approach in soccer skill research,[8,9,11,12] might limit the validity of these findings. We have recently confirmed the construct validity and reliability of new soccer skill tests of passing, shooting and dribbling[13] that determine precision, success rate and ball speed via video analysis, where test-retest reliability was determined for 20 habituated male soccer players (10 professional and 10 recreational).

In summary, evidence exists to show that fatigue can impair technical performances during exercise; however, the effects of soccer-specific exercise on technical aspects of the game remain unclear. The aim of this study was to determine whether 90 min of soccer-specific exercise would influence the quality of skill performances. The null hypotheses being that exercise would not influence precision, success or ball speed during shooting, passing and dribbling.

Methods

Participants

After approval from a university ethics committee, 15 youth players from a soccer team competing in the English Championship (age: 18.1 ± 0.9 y, height: 1.77 ± 0.01 m, mass: 71.1 ± 2.5 kg, estimated VO_2max: 57.3 ± 0.7 $mL \cdot kg^{-1} \cdot min^{-1}$) participated in the study. All participants were informed about the potential risks of the study and gave written informed consent for their participation; parental consent was obtained where players were less than 18 y of age. Players were recruited on the basis that they had no injuries, were nonsmokers and had regularly participated in training with the youth side of a Championship team for at least twelve months before the start of the study.

Experimental Design

Participants attended at least four preliminary visits before completing the soccer match simulation (SMS). Maximum oxygen uptake was estimated on the first visit using the multistage fitness test (MSFT)[14] in order to calculate the running speeds during the main trial. Maximum 15 m sprint speeds were measured during the second visit in order to ensure that sprints in the first 15 min of the SMS represented maximal effort (ie, exceeded 95% of maximal). The remaining visits habitualized participants with the exercise and skill components of the SMS. In addition, 10 participants completed 45 min of the SMS on two separate days (within 14 d) to determine the reliability of performance, physiological and metabolic responses.

Participants were asked to refrain from strenuous physical activity and caffeine consumption during the 2 d before all testing sessions. At the completion of the study, participants gave their verbal confirmation that they had complied with all instructions.

Main Trial Procedures

Participants arrived at 10:15 in pairs according to their estimated aerobic capacity (within 0.5 decimal levels on MSFT). Upon arrival, participants emptied their bowels and bladder before measurements of body mass (model 770; Seca Ltd, Birmingham, UK) and stature (Portable Stadiometer; Holtain Ltd, Wales, UK). Participants then rested for approximately 20 min before providing a preexercise blood sample. A 20 min standardized warm-up (consisting of running, dynamic stretching and ball skills) was completed before starting the SMS at 11:00. Upon completion, blood samples were taken and body mass was measured. A schematic of the main trial is presented in Figure 1.

Soccer Match Simulation (SMS)

The exercise protocol was similar to that devised by Nicholas et al,[15] but included backward movements, lateral movements, more jogging, and half-time to further replicate the demands of soccer match play.[16] Ninety minutes of intermittent activity was completed in two 45 min halves separated by a 15 min recovery period (half-time). Movements were dictated by audio signals from CDs. Assessments of soccer shooting, passing, and dribbling were completed throughout the protocol (Figure 1).

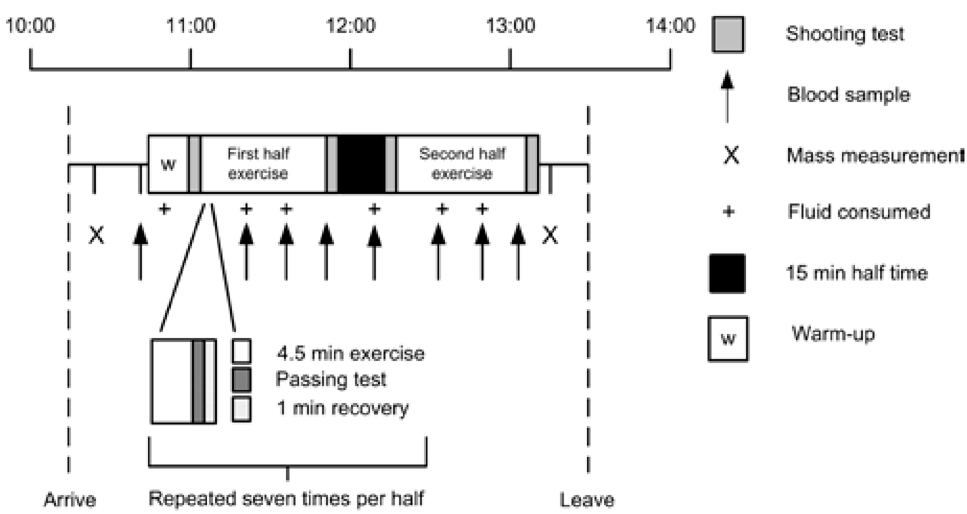

Figure 1 — Schematic of the main trial procedures.

More specifically, exercise was made up of 4.5 min blocks consisting of three repeated cycles of three 20 m walks, an alternating 15 m sprint or a 20 m dribble test, a 4 s passive recovery period, five 20 m jogs at a speed corresponding to 40% VO_2max, one 20 m backward jog at 40% VO_2max and two 20 m strides at 85% VO_2max, where movement speeds were calculated using the participant's MSFT. A passing test (1 min) and a 1 min recovery were completed after all blocks of exercise. Seven blocks of intermittent exercise and skill testing were completed during each half of exercise. Participants covered a total distance of 10.1 km and completed 56 passes, 16 shots, and 21 dribbles.

Blood samples were taken before exercise (preexercise); at half-time; and at 15, 30, 45, 60, 75, and 90 min of exercise. Tests were performed on a synthetic running track in an indoor training facility. Environmental conditions were measured at the start of exercise (ETHG-912; Oregon Scientific, USA; temperature: 20.3 ± 0.5°C; barometric pressure: 755 ± 2 mmHg; humidity: 65 ± 2%). Heart rate (HR) was continuously recorded using short-range telemetry (Polar S610; Polar, Finland) and categorized into four HR Zones (HR Zone 1: <70% HRmax, HR Zone 2: 70–79% HRmax, HR Zone 3: 80–89% HRmax, and HR Zone 4: 90–100% HRmax). Ratings of perceived exertion (Borg Scale: 6–20) were obtained after each block of exercise and sprint times were measured (Brower timing gates; Utah, USA). Equal volumes of water were consumed at 10 min before commencing each half and after 15, 30, 60, and 75 min of exercise (overall rate of fluid consumption was 14 $mL \cdot kg^{-1} \cdot h^{-1}$ BM).

Skills Testing

Figure 2B shows a schematic of the shooting and passing skill tests. Balls (Aerow: size 5; Nike Inc, USA) were released from a ramp at a constant speed of 2.3 $m \cdot s^{-1}$ toward a 1.5 × 1.5 m square (action zone). Participants jogged from the starting position to the action zone and kicked the ball toward one of four randomly determined passing or shooting targets (identified by a custom lighting system). Motion sensors at the bottom of ball delivery ramp ensured repeatability. A delay of 0.64 s existed between target identification and the ball reaching the center of the action zone.

The 2.0 × 1.0 m passing targets were placed at distances of 4.2 m (short pass) and 7.9 m (long pass) from the center of the action zone. Each target had a 0.50 × 0.25 m target box located at ground level. The shooting target was a standard 11-aside soccer goal measuring 7.33 × 2.44 m with transparent netting stretched across it. Four target lights were positioned 1.0 m horizontally inside each post and 0.5 m vertically inside the upper and lower edges of the goal. Targets were placed in the corners of the goal as this has been identified as optimal ball placement to beat a goalkeeper when shooting.[11]

The participants were instructed to aim passes at the center of the target box and illuminated target within the goal. The bouts of passing and shooting consisted of four attempts. The ball was alternately delivered from the right and left side. To enhance ecological validity, no additional touches were allowed to control the ball[17] and participants kicked the ball with the foot that they felt was most suitable to complete the task.

The dribbling task was similar to that employed by McGregor et al[7] with start and finish lines placed 20 m apart. Cones 2 through 7 were placed 3 m apart (Figure 2A). Participants dribbled the ball as fast and as accurately as possible between all cones. Participants dribbled toward a video camera that was placed directly in line with the cones.

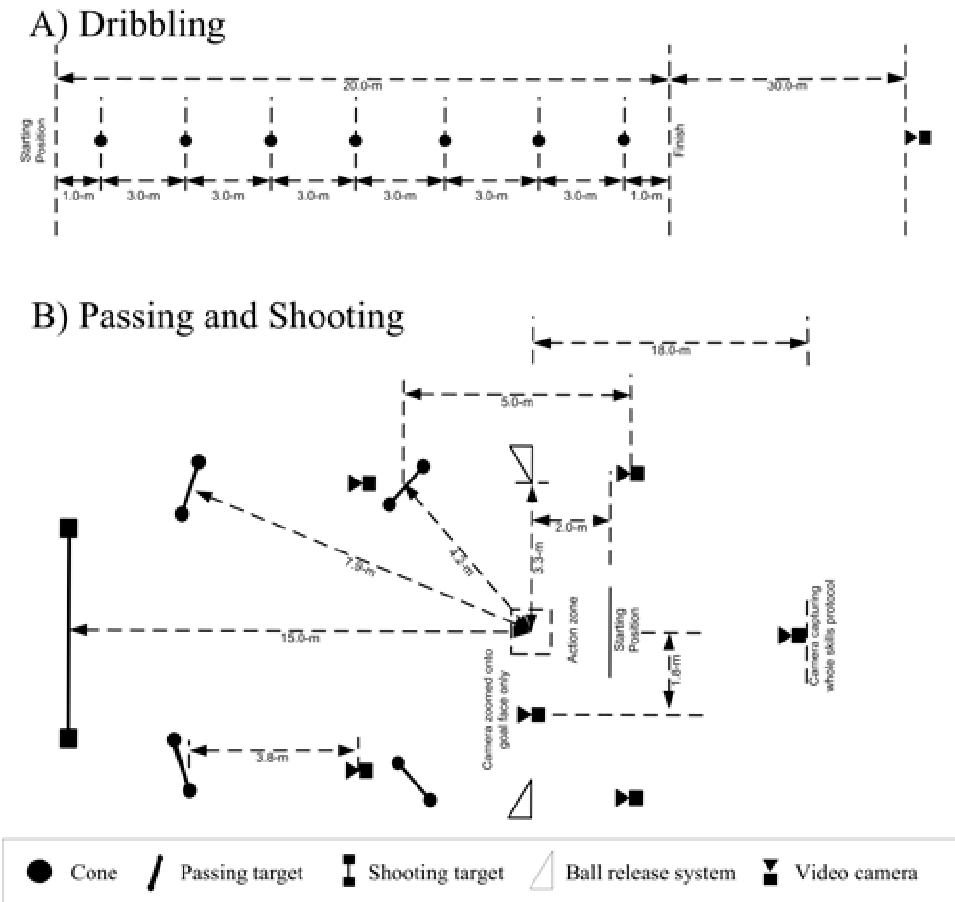

Figure 2 — Schematic of dribbling test (A) and passing and shooting tests (B).

Skill Analysis

Video footage of the skill tests were captured using 50 Hz video cameras (DCR-HC96E; Sony Ltd, UK) that were placed in the positions shown in Figure 2. Precision, percentage success, and average ball speed were calculated for all skills as previously described.[13] Ball position was digitized at the frame corresponding to ball impact on the target (passes and shots) and where the ball was perpendicular to cones (dribbling). Success in passing and shooting was defined as skills that were executed within the confines of the action zone and the ball contacted the correct target box or goal. During dribbling, if a cone was touched or was not completed in the required direction, the cone was unsuccessfully negotiated. Average ball speeds were calculated for all skills (Quintic Coaching 4.01 version 14; Quintic Consultancy Ltd, UK). The construct validity and test-retest reliability of these procedures has been previously confirmed.[13]

Blood Sampling and Analyses

Fingertip blood samples were taken at rest (preexercise), 10 min into half time (half-time) and every 15 min during exercise (first half: 15, 30, 45 min; second half: 60, 75, 90 min). Blood lactate concentrations were analyzed using a portable microvolume lactate analyzer (Lactate-Pro; Arkray, Kyoto, Japan). Before the trial, the analyzer was calibrated in accordance with the manufacturer's guidelines. The interassay coefficient of variance for blood lactate concentrations was 4.8%.

Statistical Analyses

Statistical analysis was carried out using SPSS software (Version 16.0; SPSS Inc., USA). All results were reported as the mean ± standard error of the mean (SEM) and statistical significance was set at $P \leq 0.05$. Test-retest reliability was assessed using coefficient of variation (CV) and paired samples *t* tests between data with single time points and two way repeated measures analyses of variance (ANOVA; within-subject factors: trial × time of sample) where data contained multiple time points. For the SMS, paired samples *t* tests were used to compare skill variables (ie, speed, precision, success) between halves and a one way repeated-measures ANOVA (within-subjects factor: time of sample) was used where appropriate. Mauchly's test was consulted and Greenhouse-Geisser correction was applied if the assumption of sphericity was violated.

Results

Test-Retest Reliability of Responses to SMS

The repeatability of physiological, metabolic, and performance responses to the SMS was tested in 10 players (age: 16.9 ± 0.8 years, height: 1.76 ± 0.02 m, mass: 68.6 ± 2.5 kg) who completed two additional 45 min sessions of the SMS (T1 and T2). Mean HR (T1: 170 ± 2 bpm, T2: 169 ± 1 bpm, $P = .890$; CV = 2.6%) and peak HR (T1: 198 ± 2 bpm, T2: 194 ± 2 bpm, $P = .708$; CV = 2.3%) were similar between trials. Similarly, lactate concentrations (T1: 8.4 ± 0.5 mmol·L^{-1}, T2: 8.1 ± 0.9 mmol·L^{-1}, trial effect: $F_{(1,9)} = 0.046$, $P = 0.834$; CV = 16.1%), sprint speeds (T1: 5.8 ± 0.1 m·s^{-1}, T2: 5.8 ± 0.1 m·s^{-1}, trial effect: $F_{(1,9)} = 0.031$, $P = 0.865$; CV = 2.1%), and sweat losses (T1: 1.0 ± 0.1 kg, T2: 1.0 ± 0.1 kg; $P = .845$, CV = 13.5%) did not differ between trials

Physiological Demand and Exercise Intensity

Blood lactate concentrations were elevated above resting values from 15 min of exercise (time of sample effect: $F_{(7,98)} = 30.395$, $P < .001$; Figure 3A) with values at 90 min being 7 ± 1 mmol·L^{-1}. Similarly, ratings of perceived exertion were elevated throughout exercise (time of sample effect: $F_{(7,98)} = 156.259$, $P < .001$; Figure 3B).

Sprint speed reduced over the course of the protocol (time of sample effect: $F_{(5,70)} = 7.469$, $P < .01$) with sprints in the final 15 min of exercise being 5 ± 1% slower than those in the first 15 min (75–90 min vs 0–15 min: 5.8 ± 0.1 m·s^{-1} vs 6.1 ± 0.1 m·s^{-1}, $P = 0.049$). During the SMS, mean HR was 173 ± 2 bpm and peak HR was 199 ± 2 bpm. The proportion of time spent at each relative intensity was 9.9 ± 1.5%, 20.2 ± 1.2%, 37.9 ± 4.0%, and 32.1 ± 5.7% for HR zones 1–4, respectively.

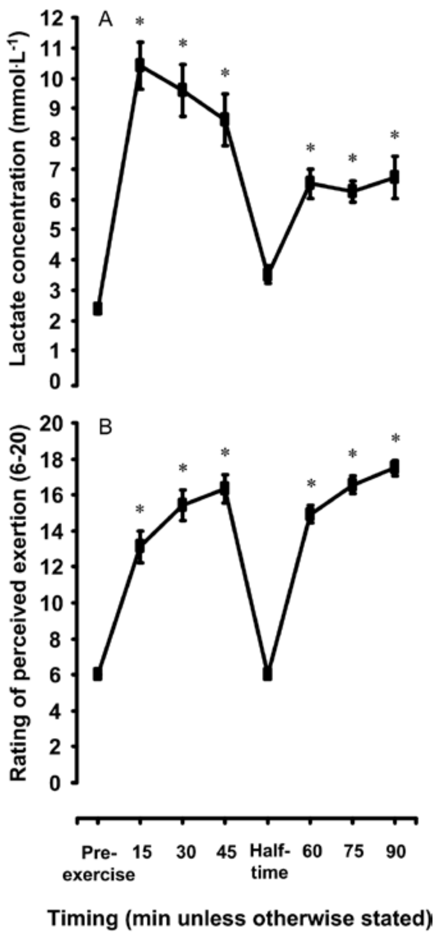

Figure 3 — Blood lactate concentrations (A) and ratings of perceived exertion (B) throughout the main trials. *Pairwise differences from preexercise and half-time values ($P < .05$).

The mean volume of fluid ingested was 1490 ± 50 mL and body mass declined from initial values with average sweat losses of 2.0 ± 0.1 kg.

Effect of Exercise on Skilled Performance

Shooting precision was affected by exercise ($F_{(3,42)} = 3.134$, $P = .035$; Figure 4A) with deviations being 31 ± 16 cm and 38 ± 16 cm greater at the end of the first and second halves respectively when compared with the correspondent prehalf values. Shots taken after exercise were 25.5 ± 4.0% less accurate than those taken before exercise. Shooting success was 70 ± 3% and remained unchanged throughout the trial (time of sample effect: $F_{(3,42)} = 1.323$, $P = .280$; Figure 4B) and between halves ($P = .072$). Although exercise did not influence shot speed throughout the trial (time of sample effect: $F_{(3,42)} = 2.142$, $P = .109$, Figure 4C), being 16.8 ± 0.2

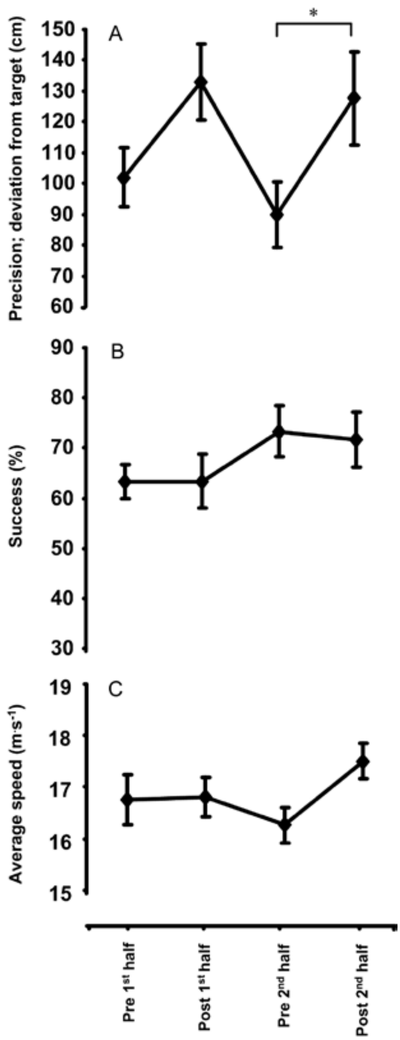

Figure 4 — Precision (A), success (B), and average speed (C) values for shooting. *Pairwise difference ($P < .05$).

m·s^{-1}, shots in the second half were slower than shots in the first half (First half: 17.3 ± 0.3 m·s^{-1}; Second half: 16.6 ± 0.3 m·s^{-1}, $P = 0.012$).

Passing precision remained unchanged during exercise (time of sample effect: $F_{(5,70)} = 0.477$, $P = .792$; Table 1) and between halves ($P = .816$), with the mean value throughout the protocol being 33 ± 1 cm. Passing success remained similar throughout exercise (time of sample effect: $F_{(5,70)} = 0.769$, $P = .575$; Table 1) and between halves ($P = .785$), with the mean success rate throughout the protocol being 61 ± 2%. However, the speed of passing was significantly reduced over 90 min of exercise (time of sample effect: $F_{(5,70)} = 3.209$, $P = .011$; Table 1) with

Table 1 Precision, success, and average speed for passing and dribbling

Skill and Variable	Timing (in Minutes Unless Otherwise Stated)							
	0–15	15–30	30–45	45–60	60–75	75–90	First Half	Second Half
Passing								
Precision (cm)	31.7 ± 1.6	33.6 ± 3.1	32.5 ± 2.1	34.2 ± 1.9	33.1 ± 1.8	30.4 ± 1.5	32.4 ± 1.5	32.8 ± 1.4
Success (%)	62.8 ± 3.4	57.5 ± 6.0	60.8 ± 4.2	57.8 ± 3.3	61.7 ± 4.5	67.5 ± 4.5	60.7 ± 3.0	61.7 ± 2.3
Speed ($m \cdot s^{-1}$)	13.3 ± 0.5	13.2 ± 0.5	12.7 ± 0.6	12.2 ± 0.5	12.3 ± 0.5	12.1 ± 0.6†	13.0 ± 0.5	12.2 ± 0.5*
Dribbling								
Precision (cm)	51.4 ± 1.7	52.2 ± 2.0	52.9 ± 2.3	51.3 ± 2.3	54.9 ± 1.9	52.4 ± 2.8	51.9 ± 1.6	52.5 ± 2.0
Success (%)	90.7 ± 1.9	90.7 ± 3.4	90.7 ± 3.4	91.9 ± 2.4	92.0 ± 2.4	96.0 ± 2.2	90.7 ± 2.2	92.6 ± 2.0
Speed ($m \cdot s^{-1}$)	4.2 ± 0.1	4.2 ± 0.1	4.1 ± 0.1	4.1 ± 0.1	4.3 ± 0.1	4.1 ± 0.1	4.2 ± 0.1	4.2 ± 0.1

*Significant difference compared with first half ($P \leq .05$). †Significant difference compared with 0–15 min ($P \leq .05$).

passes in the last 15 min of the protocol being 7.8 ± 4.3% slower than those in the first 15 min. In addition, pass speed reduced in the second half compared with passes performed in the first half (First half: 13.0 ± 0.5 $m \cdot s^{-1}$; Second half: 12.2 ± 0.5 $m \cdot s^{-1}$, $P = 0.039$; Table 1).

Dribbling precision was not influenced by exercise (time of sample effect: $F_{(5,70)} = 1.126$, $P = .355$; Table 1), with mean deviation being 52 ± 1 cm from the center of the cone. Similarly, exercise did not affect success or average ball speed during dribbling (time of sample effect: $F_{(5,70)} = 0.901$, $P = .485$; $F_{(1,14)} = 0.008$, $P = .932$ respectively; Table 1). Values of dribbling precision, success, and average ball speed remained consistent between the first and second halves of the SMS ($P = .516$, $P = .345$, $P = .879$ respectively, Table 1).

Discussion

The primary finding was that fatigue induced by a soccer match simulation (SMS), which included ball skills throughout exercise, caused a reduction in passing and shooting performances during the second half. In addition, physiological, metabolic and performance responses to the SMS were similar between repeated trials. Therefore, the SMS is a suitable measurement tool for examining the physiological, metabolic and performance (both physical and skilled) responses to interventions in soccer players.

The results demonstrate that soccer-specific fatigue influences the performance of skills throughout simulated match play. More specifically, passing speed and shooting precision decreased throughout exercise. These findings are in general agreement with previous research, where modifications in speed and/or precision of sports skills have been reported under fatiguing conditions[8,18] and exemplify the importance of measuring precision and speed of skills. These data provide additional evidence for a speed-accuracy trade-off,[19] where participants modify speed and/or precision to maintain performance.

Some studies have reported reductions in physical performances between the first and second halves of a soccer match;[2] however, few studies have evaluated temporal changes in the technical aspects of game-play. These results show that the speed of passing and shooting reduced between halves. Although this finding reflects declining performance, the extent to which ball speed impacts upon success during match play remains unclear. Nevertheless, skills performed in the second half have been observed to be less successful than skills performed in the first half during match play.[20] This is the first study to evaluate decay in the quality of skills performed during soccer-specific exercise using sensitive methods of assessment because previous studies have tested skills before and after exercise[6–8,12] and/or used criterion-based outcomes.[8–12]

Throughout actual match play, Rampinini et al[9] observed reductions in short passing performances. However, Currell et al[10] reported that kicking performance remained similar throughout simulated match play. Inconsistencies between criterion-based outcome measures (ie, scored in terms of accuracy and time faults added for errors) that are common in soccer skill research[8–12] could explain the lack of agreement between authors. The current study describes the influence of soccer-specific fatigue on skilled performance in units that have strong ecological validity rather than criterion-based measurements; hence, comparison with previous research is difficult. Notably, the disagreement that exists between researchers concerning technical responses to fatigue might be lessened with the introduction of more sensitive and ecologically valid outcome measures.

The findings from this study, in combination with that of previous authors,[7,21] suggest that soccer dribbling is more resilient to the effects of match-related fatigue than other skills involving greater peak muscular activity. McGregor et al[7] showed that fluid abstinence during intermittent exercise resulted in a 5% decline in the performance of a timed dribbling task. Although this earlier research highlights a potential decline in skilled performance resulting from dehydration,[22] dribbling performance remained unchanged throughout exercise in players who were in a physiological state that is more representative of that advocated by professional sports teams (ie, consumed a carbohydrate-free solution throughout exercise). We observed no changes in dribbling performance during the SMS despite reductions in sprint speed, highlighting the potential shortcomings of timed dribble tests whose outcomes are heavily influenced by sprint speed.[6,7] In addition, this study employed a standardized diet and two days of rest before participants began the SMS. It can, therefore, be assumed that these participants started exercise in a physiological state that is generally recommended for team players; thus, enhancing the ecological validity of these findings.

Although other protocols exist that simulate soccer match play,[15,23] the ecological validity of these simulations is limited by the omission of backward and sideways movements, the lack of game specific skills, and the failure to include a half-time period. The SMS includes passing, shooting, and dribbling throughout two halves of soccer-specific exercise separated by a 15 min half-time. The number of dribbles and on-the-ball movements correspond to those reported throughout match play[24] and participants covered 10.1 km, which represents average distances traveled by soccer players during match play.[1,2] Furthermore, HR and blood lactate concentrations were reflective of match play[25] and the proportion of time spent in the relative exercise intensities (HR zones 1–4) was similar to previous findings.[26] In addition, the SMS was repeatable as demonstrated by the lack of differences between the physiological, metabolic, and performance responses elicited in two 45 min SMS trials.

The mechanisms of match-related fatigue involved in soccer are likely to be multifaceted in origin, where muscle damage could influence proprioception and glucose transportation into active muscle; nevertheless, compromised fiber-specific muscle glycogen levels,[25] hypohydration,[6,22] and reduced blood glucose concentrations have all been proposed as possible contributors. Throughout the current study, fluid was consumed in accordance with published guidelines[27] and in a manner that replicates professional sports teams; therefore, although mass losses occurred throughout exercise, it is unlikely that the effects of exercise on skilled performance reflect changes in fluid balance. Glucose is the principle energy source for cerebral metabolism and the brain is dependent upon a continuous supply of circulating blood glucose. It is plausible, therefore, that exercise can cause skill decrements due to reductions in the integrity of the central nervous system.[28] However, as no measure of cerebral or muscle glucose concentrations were taken, although attractive, this mechanism remains speculative.

Proficient skill performance is affected by cognitive factors such as decision making and game intelligence. The randomized lighting system used for target identification incorporated perceptual abilities, such as decision making and visual searching. Although we were unable to determine the direct involvement of these cognitive aspects of performance in the decrement in shooting and passing observed, the development of a sensitive measure of soccer skill performance that incorporates perceptual skills and reflects the demands of competition, could increase the ecological validity of these findings.

Royal et al[29] suggested that elite athletes are more resilient to physiological stresses that occur during competition, and thus better able to maintain technical proficiency. The participants in this study had at least one years playing and training experience with a professional academy; despite training and playing on three occasions per week during the competitive season, reductions in passing and shooting performance were observed during the protocol. As the decline in skill has been found to be more severe in novices than seniors,[30] it remains to be elucidated whether the effects of fatigue upon skilled performances observed throughout exercise in junior players in this study and others[9] also impact upon senior level players.

Practical Applications and Conclusions

In summary, despite dribbling performance being maintained, soccer passing and shooting skills were observed to decline throughout exercise; therefore, practitioners should be aware that passing and shooting are susceptible to fatigue during soccer match play. Future research should focus on interventions that attenuate reductions in skilled performance. In addition, the physiological, metabolic and performance responses to the SMS demonstrated test-retest repeatability and were representative of match play. The SMS protocol can be used to evaluate the effects of interventions on soccer players.

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